SEA, Ltd. PROJECT NO. 801747	ISSUE DATE: September 1, 2009

THOMPSON, COE, COUSINS & IRONS, L.L.P.
Attention: Mr. Barry A. Moscowitz & Ms. Heather H. Sauter
700 North Pearl Street, Twenty-Fifth Floor
Dallas, Texas 75201-2825

EXAMINATION OF A BROKEN SLAT CONVEYOR BAR

Bruner v. Cedarapids, Inc., et al.
Civil Action No. 3-08CV1163-M

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I. PROJECT SUMMARY

PROJECT ASSIGNMENT

On May 21, 2009, SEA was requested by Mr. Barry Moscowitz and Ms. Heather Sauter of Thompson, Coe, Cousins & Irons, L.L.P., to investigate the alleged failure of a slat conveyor bar (Cedarapids, Inc. Part Number 4430-028-06; Allied-Locke Industries, Inc. Part Number 10959) during installation of a new chain conveyor for a Cedarapids, Inc. CR351 Asphalt Paver at the Conley Lott Nichols of Texas facility in Irving, Texas, on June 15, 2006. This investigation was assigned to the direction of Dr. Nicholas E. Biery as SEA Project No. 801747.

SCOPE OF PROJECT

Specifically, SEA was asked to examine the remaining portion of the slat conveyor bar purported to have been involved in the June 15, 2006 incident, and determine if any manufacturing defects were present. Additionally, SEA was asked to review expert reports and foundry data and to comment on the role of part inspection in detecting manufacturing defects.

CONCLUSIONS

- **No manufacturing defects were found during the July 24, 2009 joint evidence examination.**
- **Destructive and non-destructive testing of the bar reported to have been involved in the incident (incident bar) revealed that the microstructure, chemistry, strength, ductility, and hardness were typical of a ductile iron casting.**
- **Tensile testing of a sample cut from the incident bar met the requirements for ductile iron grade 65-45-12 as specified in ASTM A536-84.**
- **Material testing results produced by the foundry that produced the slat conveyor bar (Tailong Hardware and Machine Company) similarly met the property requirements of ASTM A536-84.**
- **Inspection could not have prevented the incident since the mechanical tests of the incident bar met the required mechanical properties and no manufacturing defects were found.**

II. PROCEDURES

1. SEA Technical Consultant Nicholas Biery, Ph.D., attended an evidence exam conducted on July 10, 2009, where the following testing was conducted:

   - Tensile bars were cut from the bar reported to have been involved in the incident (the incident bar), as well as from a bar which was reported to have been taken from the conveyor chain assembly in the fully reconditioned asphalt paver reported to have been involved in the incident (the exemplar bar).
   - Wet fluorescent magnetic particle (WFMT) inspection was conducted on the incident bar and on the tensile samples machined from the incident bar and the exemplar bar.
   - The tensile bars were tested to determine their strength and elongation.
   - Hardness tests, chemistry evaluation, and microstructural analysis were conducted on the incident bar and on the exemplar bar.
   - Optical and SEM microscopy was conducted of the fracture surface of the incident bar before and after cleaning in a solution of Alconox® in hot water.
   - A clay replica was made near the fracture origin of the incident bar so that the radius in that location could be evaluated.

2. Information provided by Thompson, Coe, Cousins & Irons, L.L.P., was reviewed including:

   - Tensile test and chemical analysis reports conducted by the foundry which produced the bars (Tailong Hardware & Machinery Co., Ltd.) from documents attached to Bill Wang's May 29, 2009 deposition; reports identified for PO Nos. 3825 (May 27, 2004), 3898 (October 22, 2004), 4010A (September 2, 2005), and 4107A (March 28, 2006).
   - The depositions of Larry Peyton (Cedarapids, March 25, 2009), Bill Wang (Lucent Auto & Casting, May 26, 2009), Jeffery Shoemaker (Allied Locke), Joeseph Rock (Allied Locke), Heath Taylor (Conley Lott Nichols, February 10, 2009), Lloyd Bruner, Jr. (Conley Lott Nichols, February 10, 2009), William Gerlich (Cedarapids, March 25, 2009), David Crowson (Allied Locke, March 17, 2009), Judd Burr (Conley Lott Nichols, February 10, 2009), Hal Watson, Jr. (Watson Engineering Corporation, August 13, 2009), George Prause (MSI Testing and Engineering, Inc., May 20, 2009), Mark Lynn Bruner (plaintiff, February 9, 2009), Art Albee (Allied Locke, April 30, 2009), Gregg Austin (Cedarapids, May 18, 2009), Joseph Musil (Cedarapids, May 18, 2009), Joseph Rock (Allied Locke, March 18, 2009).
   - Three reports by Mr. Ray Schiltz titled "Inspection of a Broken Slat Conveyor Bar Preliminary Report – Document List" (May 26, 2009), "Investigation of a Broken Slat Conveyor Bar Preliminary Report" (May 26, 2009), and "Investigation of a Broken Slat Conveyor Bar Third Report" (August 8, 2009).

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- A July 12, 2009 report by Mr. Hal Watson titled "Accident Causation and Mechanical Engineering Report".
- Documents attached to George Prause's deposition, including the MSI chemistry Report No. 103741 reportedly performed on the small "ear" taken from the incident bar.
- Photographs of the incident bar and of the Cedarapids paver.
- Various manuals for Cedarapids pavers.
- United Cast Bar Limited product literature for "Continuous Cast Iron Grade: Unibar - 80-55-06", referenced in other reports and depositions as a "standard".
- "Defendant Allied-Locke Industries, Inc.'s Answers and Objections to Plaintiff's Second Set of Interrogatories".
- "Defendant, Cedarapids, Inc.'s Responses to Plaintiff's Requests for Admission".
- "Plaintiff's First Amended Petition".
- "Defendant Cedarapids' Answer to Plaintiff's First Amended Petition".
- "Plaintiff's Supplemental Answers to Defendants Interrogatories".
- "Defendant Allied-Locke Industries, Inc.'s First Amended Answer".
- "Defendant, Cedarapids, Inc.'s Answers to Plaintiff's Second Set of Written Interrogatories".
- "Defendant, Cedarapids, Inc.'s Fourth Supplemental Responses to Plaintiff's First Requests for Production".
- "Defendant, Cedarapids, Inc.'s Fifth Supplemental Responses to Plaintiff's First Requests for Production".
- Purchase orders and invoices for several orders of Model 300 Slat Bars per DWG#CD1573, Cedarapids part # 0443002806, Allied-Locke code 09704 207 10.
- Allied-Locke Ind. Drawing 10959, Drawing Number CD1573-1, dated January 24, 2004.
- "Defendant, Cedarapids, Inc.'s Responses to Plaintiff's Second Requests for Production".

3. Other documents:

- ASTM A536-84 (reapproved 04), Standard Specification for Ductile Iron Castings.
- The ASM Handbook, Volume 15, section titled "Ductile Iron", pp. 647-677.

III. DISCUSSION

On June 15, 2006, Conley Lott Nichols of Texas (Conley Lott) employees were reportedly installing a new slat conveyor chain in a Cedarapids, Inc. (Cedarapids) asphalt paver when one of the slat bars fractured, striking Mr. Mark Lynn Bruner in the face and causing injuries to Mr. Bruner. Subsequent to the accident, the broken slat bar (incident bar) was returned to Cedarapids for warranty replacement with a report of the circumstances of the failure. Allied Locke Industries, Inc. (Allied Locke) was the supplier of the slat bar to Cedarapids, and had in turn purchased the slat bar from a Chinese foundry named Tailong Hardware & Machinery Co., Ltd. (Tailong) through Lucent Auto & Casting (Lucent). According to Joe Shoemaker of Allied Locke, Cedarapids supplied a portion of the slat bar to Allied Locke where chemistry tests were performed on a portion of the broken slat bar. Initial tests by Allied Locke, which were subsequently found to have been performed incorrectly, determined that the carbon level in the incident bar was significantly higher than expected. Cedarapids put further sale of the cast slat bars for this model paver on hold while the quality of the slat bars was investigated, returning the bars to Allied Locke. Retesting of the incident bar by an independent lab (MSI) found that the carbon level was typical for ductile iron, and Allied Locke sold the remaining bars to Roadtec's AS Parts Division.

On July 10, 2009, SEA Technical Consultant Nicholas Biery, Ph.D., traveled to the Euless, Texas, laboratory of AADFW, Inc. for examination and destructive testing of the remaining portion of the incident bar. Prior to the examination, all parties had agreed to a testing protocol that included machining and testing of a sub-sized tensile specimen from the remaining portion of the incident bar, microscopic examination of its fracture surface, polishing and etching of a portion of the incident bar to evaluate its microstructure, Brinell hardness testing, and chemical analysis. To obtain a comparison with another bar not involved in the incident, some of these tests were repeated on a bar reportedly removed from the new slat conveyor assembly that was being installed during the incident (exemplar bar). In addition to the previously agreed-upon tests, the incident bar and the tensile test specimens removed from both it and the exemplar bar were subjected to wet fluorescent magnetic particle inspection (WFMT), a technique for detecting surface cracks in ferromagnetic alloys.

Although the incident bar was reported to have initially been fractured in two places resulting in three pieces, Allied Locke reported that they only received one end of the fractured bar along with one of the smaller pieces that had been broken away. The smaller piece was apparently lost after testing at MSI, so the incident bar examined consisted of one side of the original bar and bore a fracture surface on one end and a saw cut on the other. The bar was coated with deposits of black material (presumably solidified asphalt), and bore wear marks and a groove approximately ¼" deep on one side. Approximately ½" of the bar was removed for machining of the sub-sized tensile specimen to be tested according to ASTM A370, while the other portion was examined optically. Additional small samples were removed for hardness testing and evaluation of chemical composition according to ASTM E485. The fracture surface was covered with rust or oxide, and so the

specimen was cleaned in a commercial cleaner to remove the oxide. Once cleaned, the fracture surface was imaged in the SEM.

Tensile testing of the incident bar resulted in a yield strength of 64.4 ksi, a tensile strength of 89.8 ksi, and an elongation of 12.3%. The broker, Mr. Howard Wang, indicated that this foundry normally supplies ductile iron to the specification 65-45-12, which indicates that it should have an ultimate strength of 65 ksi, a yield strength of 45 ksi, and an elongation of 12%, values which were exceeded for the tensile specimen machined from the incident bar. It should be noted that ASTM A536-84 does not include acceptance criteria for chemistry or microstructure, instead relying on the mechanical properties, and that meeting strength and ductility requirements is sufficient under that standard. The properties measured in this tensile sample easily met the requirements of the grade that the foundry indicates it supplied. Finally, it should be noted that it is normal to test the properties for cast irons in a separately cast part of standardized dimensions. Mr. Wang indicated that tests were conducted on the heats of ductile iron supplied, and provided test data for these heats at his deposition. The mechanical properties provided by Mr. Wang also exceed the requirements for 65-45-12.

Microstructural examination of the incident bar revealed that the graphite was predominantly spheroidal even in the "worst"[1] locations examined, and was consistent with a pearlitic ductile iron as would be expected from the tensile properties measured in the incident bar. There is no requirement in ASTM A536 for a given level of nodularity. It should be noted that magnesium is the element added to ductile irons to produce the nodular graphitic structure, and the level of magnesium measured in the incident bar was 0.04% (it was higher in the exemplar bar). The ASM Handbook, volume 15, indicates that 0.04 to 0.06% magnesium is typically required, and that the level may be slightly lower for sulfur contents below 0.015% as was the case for both the incident and exemplar bars.

Test conducted on the exemplar bar revealed somewhat lower strength and elongation values along with less fully spheroidal graphite in the microstructure, though the tensile tests still exhibited elongations over 5% indicating that they did possess a reasonable level of ductility. Although this microstructure of this exemplar bar is perhaps not ideal, it should be noted that Cedarapids did not specify a specific grade of ductile iron for the conveyor slat bar. Instead, Cedarapids simply stated on the drawing that the part should be made from "ductile iron or cast steel". Absent requirements for strength, ductility, nodularity, or other parameters, it is difficult to argue that the bar failed to meet a performance requirement that was not transmitted to either Allied Locke or the contracted Chinese foundry, Tailong Hardware and Machine Company.

Initial wet fluorescent magnetic particle examination (WFMT) of the incident bar revealed several indications oriented parallel to the wear marks present on the surface of the bar. Light polishing with abrasive paper removed the larger indications, indicating that the indications were due to surface phenomena (mostly likely deep scratches) rather than significant cracking. WFMT is often selected because it is capable of detecting very small defects, is often identifies features such as deep scratches. WFMT was also applied to the machined tensile specimens prior to testing and failed to identify any cracks.

[1] "Worst" as indicated in Figure 7 of Ray Schiltz's "Investigation of a Broken Slat Conveyor Bar Third Report"

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The rust on the fracture surface prevented observation of the fine fracture surface details, so the sample was cleaned in a solution of Alconox® in hot water. Subsequent to cleaning, the sample was imaged in the SEM. Examination of the fracture surface of the incident bar revealed a predominantly spheroidal morphology of graphite, and did not reveal any defect at the fracture origin.

One issue that has been raised in the other expert reports is the role of inspection and/or testing in ensuring the quality of castings. In this case, examination of the incident bar failed to reveal any defects associated with the fracture, and the mechanical properties exceed the grade that the foundry reported supplying. In such a scenario, inspection would not be able to detect a defect that is not present, and it similarly could not detect a failure to meet mechanical properties when this part did meet the mechanical properties for the grade supplied by the mill. It should be noted that Cedarapids did not specify any particular grade or performance level (strength or ductility) for the part, so even if testing were to be performed there would be no minimum values for it to fail to meet. Finally, it must be understood that for low cost parts (Mr. Wang's deposition indicated that the parts were being sold to Allied Locke for $6.74, who in turn sold them to Cedarapids for approximately $18.54 according to Defendant Cedarapid's Answers to Plaintiff's Second Set of Written Interogatories), inspection or testing is usually performed on a small subset of parts because the cost of inspection for each component is cost prohibitive (note that Allied Locke outsourced the parts due to cost pressure). Since the incident bar exceeded the requirements and was without identifiable defect, it is unlikely that a practical inspection and/or testing program would have identified an issue even if some of the bars failed to meet performance requirements.

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IV. SIGNATURES

SEA, Ltd. hereby certifies the expressed opinions and conclusions have been formulated within a reasonable degree of professional certainty. They are based upon all of the information known by SEA, Ltd. at the time this report was issued, as well as knowledge, skill, experience, training, and/or education.

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PROFESSIONAL RESUME OF NICHOLAS E. BIERY, Ph.D.

September 2008

I. General Information

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II. Education

Doctor of Philosophy
Materials Science & Engineering
Carnegie Mellon University
Pittsburgh, Pennsylvania
December 2000

Master of Science
Materials Science & Engineering
Carnegie Mellon University
Pittsburgh, Pennsylvania
May 1996

Bachelor of Science
Materials Science & Engineering
University of Tennessee
Knoxville, Tennessee
May 1995

III. Professional Summary

August 2008 to Present
Technical Consultant
SEA, Ltd.
Columbus, Ohio

Investigation of materials failures and other aspects of materials performance. Duties include performing and supervising the testing of samples, analysis of test results, collection and preparation of written reports of findings. Expert testimony provided, as required.

March 2008 to August 2008
Senior Engineering Specialist, Materials & Fabrication Group Lead
ExxonMobil Upstream Research Company
Houston, Texas

Coordinated materials research and project support, with focus on pipeline welding research. Duties included research planning and stewardship, project support for materials and welding, allocation of personnel and budget, development and maintenance of interfaces with other ExxonMobil upstream companies and affiliates, and presentation of group activities.

February 2007 to February 2008
Senior Engineering Specialist, Pipelines Group Lead
ExxonMobil Upstream Research Company
Houston, Texas

Responsibilities included coordination of pipeline research activities and pipeline project support. Responsible for technical support of ExxonMobil pipeline projects. Coordinated research company efforts to resolve key technical issues for major arctic pipeline project. Lead technical interface for qualification of high-strength pipeline materials.

January 2005 to January 2007
Engineering Specialist
ExxonMobil Upstream Research Company
Houston, Texas

Research company lead for high-strength linepipe qualification. Duties included oversight of contractors (fabrication, large-scale testing, analytical studies, and computational modeling), evaluation of incentives for the use of high-strength linepipe, and maintaining relationships with steel pipe mills.

February 2001 to December 2004
Senior Research Engineer
ExxonMobil Upstream Research Company
Houston, Texas

Technical lead for development of high-strength cryogenic steel plate. Responsibilities included being the primary contact for plate mill interactions, lead for external programs on low-temperature biaxial testing and neutron diffraction measurement of residual stresses, analysis and presentation of program results and test data.

August 1995 to December 2001
Graduate Research Assistant
Carnegie Mellon University
Pittsburgh, Pennsylvania

Development of software and experimental techniques for measurement of small strains in titanium aluminides. Set up new in-SEM tensile testing stage, designed and manufactured wedge-action grips, and conducted tensile tests of titanium aluminide samples. Applied statistical methods to characterize variability in cast gamma-TiAl.

IV. Publications

W.C. Kan, M. Weir, M.M. Zhang, D.B. Lillig, S.T. Barbas, M.L. Macia, and N.E. Biery, "Strain-Based Pipelines: Design Consideration Overview," in Proceedings of the Eighteenth International Offshore and Polar Engineering Conference, 2008, pp. 174-180.

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K. Minnaar, P. Gioielli, M. Macia, F. Bardi, N. Biery, W. Kan, "Pressure Effects on Strain Concentration and Constraint for Strain-Based Design," in Proceedings of the Seventeenth International Offshore and Polar Engineering Conference, 2007, pp. 3114-3120.

D.P. Fairchild, W. Cheng, S.J. Ford, K. Minnaar, N.E. Biery, A. Kumar, and N.E. Nissley, "Large-Scale Testing Methodology to Measure the Influence of Pressure on Tensile Strain Capacity of a Pipeline," Ibid., pp. 3013-3022.

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A. Lucci, G. Mannucci, G. Malatesta, N.E. Biery, "Evaluation of the Resistance of X120 Pipe to Mechanical Damage," in Proceedings of the 6^{th} International Conference, ASME, New York, New York, 2006, IPC2006.

N. Biery, M. Macia, R. Appleby, D. Fairchild, D. Hoyt, D. Dorling, D. Horsley, "Godin Lake Trial: X120 Field Welding," in Proceedings of the 6^{th} International Conference, ASME, New York, New York, 2006, IPC2006.

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N. Biery, M. DeGraef, and T.M. Pollock, "A method for measuring strain on a microstructural scale using an SEM equipped with an in-situ tensile substage: Application to gamma-TiAl alloys," Metallurgical and Materials Transactions A, V34, 2003, pp. 2301-2313.

N. Biery, M. DeGraef, R. Raban, A. Elliot, C. Austin, and T.M. Pollock, "Use of Weibull Statistics to Quantify Property Variability in TiAl Alloys," Metallurgical and Materials Transactions A, V33, 2002, pp. 3127-3136.

J.G. Milke, J.L. Beuth, N.E. Biery, and H. Tang, "The Effect of Constraint-Induced Normal Stress on the Failure of Notched TiAl Components," Metallurgical and Materials Transactions A, V33A, 2002, pp. 417-426.

N. Biery, M. DeGraef, and T.M. Pollock, "Influence of Microstructure and Strain Distribution on Failure Properties in Intermetallic TiAl-Based Alloys," Materials Science and Engineering A, V319, 2001, pp. 613-617.

N. Biery, M. DeGraef, and T.M. Pollock, "Study of Localized Strain at Notches in Gamma-TiAl Alloys Using Displacement Mapping and Microstructural Characterization," in Gamma Titanium Aluminides (Y-W. Kim, et al, eds.), TMS, Warrendale, Pennsylvania, 1999, pp. 557-564.

M. DeGraef, N. Biery, L. Rishel, T.M. Pollock, and A. Cramb, "On the Relation Between Cooling Rate and Solidification Microstructure in As-Cast Titanium Aluminides," Ibid., 1999, pp. 247-254.

N. Biery, T.M. Pollock, N.T. Nuhfer, and M. DeGraef, "Displacement Mapping During in-situ Straining in the SEM," Microscopy and Microanalysis, V5, 1999, pp. 334-335.

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C.R. Brooks, N.E. Biery, L. Zhaohui, X. Xiande, and Z. Datong, "Surface Morphology of Iron Dendrites in the Yanzhuang H6 Meteorite," Materials Characterization, V35, 1995, p. 165.

FEDERAL COURT QUERY
Nicholas E. Biery, Ph.D.

SEA Project No.	Case Name	Type	Date	Venue	Case No.
150905	ExxonMobil Oil Corporation vs. AMEX Construction Co., Inc. vs. ISCO Industries, LLC and Ambitech Engineering Corp.	Depo.	6/16/09	United States District Court Northern District of Illinois Eastern Division	Civil Action No. 07 CV 4278